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Optoelectronic sensor and device for 3D distance measurement

Description

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The invention relates to an optoelectronic sensor for demodulating a modulated photon flux, and to a measuring device having at least one electronic sensor and serving for 3D distance measurement by determining the propagation time 10 of a modulated photon flux.

Methods and devices for 3D object measurement are sufficiently known. Thus, DE 197 04 496 C2, inter alia, describes a photonic mixer device (PMD) which can be used for 15 measuring passive objects. The photonic mixer device contains a p-doped silicon substrate, on which at least two light-sensitive modulation photogates are arranged. Accumulation gates likewise arranged on the p-doped silicon substrate are assigned to the modulation photogates. The 20 modulation photogates are operated with a modulating push-pull voltage. Intensity-modulated light incident on the p-doped silicon substrate generates minority charge carriers which drift under the influence of the modulating push-pull voltage to the accumulation gates, where they are integrated. 25 A prerequisite for an object measurement is that a predefined phase relationship exists between the phase of the push-pull voltages and the phase of the intensity-modulated light emitted by a transmitter. One disadvantage of such a photonic mixer device can be seen in the fact that the modulation 30 photogates and the accumulation gates are applied on the silicon substrate, and thus restrict the optical sensor

region of the photonic mixer device. Furthermore, it is not possible to generate a constant drift field in the substrate with the modulation photogates arranged on the silicon substrate.

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DE 100 47 170 C2 discloses a PMD system by means of which not only the intensity but also the propagation time of an intensity-modulated light wave that is emitted by a transmitter and received by a photonic mixer device can be measured. However, the patent specification is not concerned with the realization of photonic mixer devices.

DE 198 21 974 A1 discloses a device and a method for detecting the phase and amplitude of electromagnetic waves using photonic mixer detectors. In a manner similar to the photonic mixer detector according to DE 197 04 496 C2, modulation photogates and accumulation gates are situated on a semiconductor substrate. In contrast to the modulation photogates and accumulation gates in accordance with DE 197 04 496 C2 the modulation photogates and also accumulation gates in accordance with DE 198 21 974 A1 have the form of elongate, narrow and parallel strips.

The present invention is therefore based on the object of providing an optoelectronic sensor in which the sensor region is not shaded by gates and in which an essentially homogeneous drift field can be generated.

A central concept of the invention can be seen in the fact that the drift field required for demodulating an intensity-modulated photon flux is generated directly in a semiconductor region of the sensor. A homogeneous drift field can be generated in this way. At the same time, the optical sensor region above the semiconductor region is free of electrodes and can thus be optimized in terms of its optical

properties.

The abovementioned technical problem is solved first of all by means of an optoelectronic sensor for demodulating a
5 modulated, in particular intensity-modulated, photon flux.

For this purpose, the optoelectronic sensor has a semiconductor region, which is preferably p-doped. At least two collecting zones are introduced in the semiconductor
10 region, said collecting zones for example being diffused into the semiconductor region and being doped inversely with respect to the semiconductor region. The collecting zones serve for collecting and tapping off minority carriers generated when a modulated photon flux penetrates into the
15 semiconductor region. Furthermore, at least two control zones are introduced in the semiconductor region, which control zones can generate a drift field in a manner dependent on a control voltage that can be applied to the control zones, the control zones being of the same doping type as the
20 semiconductor region.

As an alternative, the collecting zones may also be produced by local charge transfers in the semiconductor region.

25 The subclaims relate to advantageous developments.

A semiconductor substrate is expediently provided which carries or contains the semiconductor region and is doped more highly than the semiconductor region.

30 As an alternative to the more highly doped substrate, the semiconductor region may be applied as a semiconductor layer on a dielectric as well.

In order to be able to generate a sufficiently strong drift field in the vicinity of the collecting zones, the control zones are at a greater distance from the midpoint of the sensor than the collecting zones. The drift field spans the
5 collecting zones in this way.

The abovementioned technical problem is likewise solved by means of a measuring device which may serve in particular for 3D distance measurement.

10 The measuring device has at least one optoelectronic sensor as claimed in one of claims 1 to 12. Furthermore, an optical transmitter is provided which serves for generating and emitting a modulated, in particular intensity-modulated,
15 photon flux having a predetermined phase. Furthermore, a device for generating a control voltage is provided, the phase of the control voltage being in a fixed relationship with the phase of the photon flux generated by the transmitter. The collecting zones are assigned an evaluation
20 device designed for determining the amplitude and phase of the modulated photon flux with respect to the phase of the control voltage. It should be noted that the optoelectronic sensor is in principle a photonic mixer detector which may correspond for example to a pixel of a camera chip. If, in
25 the semiconductor region, more than one collecting zone pair are embedded between the two control zones, the optoelectronic sensor may also function as a multipixel sensor. In this way, a two-dimensional pixel array can also be formed through the arrangement of a plurality of
30 collecting zone pairs.

As an alternative, an optoelectronic sensor for demodulating a modulated photon flux may be provided, having a semiconductor region, at least two collecting zones present
35 at a surface of the semiconductor region and serving for

collecting and tapping off minority carriers generated when a modulated photon flux penetrates into the semiconductor region, and at least two capacitive elements for capacitively coupling in an AC voltage which generates a drift field. The 5 collecting zones are arranged between the capacitive elements.

The capacitive elements may be capacitors or reverse-biased Schottky diodes.

10 As an alternative, the capacitive elements may contain zones which are inversely doped with respect to the semiconductor region and form a pn junction with the semiconductor region, said pn junction being reverse-biased during operation.

15 The collecting zones are expediently formed as Schottky diodes which are reverse-biased during operation.

20 The invention is explained in more detail below on the basis of an exemplary embodiment in conjunction with the drawings, in which:

25 Figure 1 shows an optoelectronic sensor in cross section with a connected, schematically illustrated evaluation device, a control voltage of predetermined polarity being applied to the control zones,

30 Figure 2 shows the optoelectronic sensor according to Figure 1, a control voltage whose polarity has been reversed being applied to the control zones,

Figures 3a-e show the profile of an intensity-modulated photon flux emitted by a transmitter,

the profile of the photon flux impinging on the optoelectronic sensor shown in Figure 1,

the profile of the drift or control voltage,

5 the profile of the integrated electric current tapped off at the collecting zone 20,

and the profile of the integrated electric current tapped off at the collecting zone 22,

10 Figure 4 shows an optoelectronic sensor in cross section with a connected, schematically illustrated evaluation device and two capacitors for capacitively coupling in a control voltage into the 15 semiconductor region, and

Figure 5 shows an optoelectronic sensor in cross section with a connected, schematically illustrated evaluation device and two reverse-biased diodes for capacitively coupling in a control voltage into the 20 semiconductor region.

Figure 1 shows an optoelectronic sensor, which may also be referred to as an optoelectronic detector. The optoelectronic 25 sensor has a semiconductor region, in the present case a semiconductor layer 10, which is p-doped in the present example. Two p-doped zones 32, 34 are diffused into the semiconductor layer 10, said p-doped zones being referred to as control zones hereinafter. Furthermore, two n-doped zones 30 20, 22 are diffused into the semiconductor layer 10, said n-doped zones being referred to as collecting zones hereinafter. The collecting zones 20 and 22 and also the control zones 32 and 34 extend from a surface of the semiconductor layer into the semiconductor layer 10. With 35 respect to the imaginary midpoint of the sensor, the control

zones 32 and 34 are situated further outwardly than the collecting zones 20 and 22. A controllable voltage source 60 is connected to the control zones 32 and 34, which voltage source, as will be explained in more detail below, generates 5 a control voltage (illustrated in Figure 3c), also called drift voltage, in order to generate a homogeneous drift field in the semiconductor layer 10. Furthermore, the collecting zones 20 and 22 are assigned an evaluation device, which, for the sake of simpler illustration, is merely illustrated symbolically by the two charge meters 40 and 42. The charge 10 meter 40 is connected to the collecting zone 20 and measures the integrated current which can be tapped off at the collecting zone 20 and the temporal profile of which is shown in Figure 3d. The charge meter 42 is connected to the collecting zone 22 and can measure the integrated current 15 which can be tapped off at the collecting zone 22 and the temporal profile of which is illustrated in Figure 3e.

Figure 2 shows the optoelectronic sensor illustrated in 20 Figure 1, wherein merely the polarity of the voltage source 60 applied to the control zones 32 and 34 has been interchanged.

As shown in Figures 1 and 2, the semiconductor layer 10 is 25 applied on a dielectric 12, for example.

The text below will explain the functioning of the optoelectronic sensor in conjunction with a measuring device for 3D distance measurement with regard to an object (not 30 illustrated).

It shall be assumed that an optical transmitter (not illustrated), also called photon source, generates and emits an intensity-modulated photon flux, the profile of which is 35 illustrated in Figure 3a. The intensity-modulated photon flux

is reflected for example at an object to be measured and, after a specific photon time of flight, which is entered in Figure 3a, impinges as photon flux 50 on the active sensor zone of the optoelectronic sensor, as is illustrated in 5 Figure 1 and Figure 2. The temporally delayed photon flux 50 is illustrated in Figure 3b. The photon flux 50 penetrating into the semiconductor layer 10 generates charge carrier pairs in the semiconductor layer 10, of which charge carrier pairs only the electrons 11 functioning as minority carriers 10 are illustrated. In order to be able to measure the amplitude and phase of the photon flux 50 with respect to the phase of the control voltage, a control voltage is applied to the p-doped control zones 32 and 34, the profile of said control voltage being illustrated in Figure 3c. As illustrated in 15 Figure 1 and Figure 2, the control voltage can be generated by electronically changing over the voltage source 60. An important prerequisite for an object measurement is that the phase of the photon flux emitted at the optical transmitter is in a fixed relationship with the phase of the control 20 voltage, as is illustrated by the curve profiles illustrated in Figures 3a and 3c. The control voltage applied to the p-doped control zones 32 and 34 brings about in the semiconductor layer 10 a drift field which runs essentially homogeneously in the semiconductor layer 10 between the 25 collecting zones 20 and 22. The direction of the drift field is changed in a manner dependent on the control voltage applied to the control zones 32 and 34. In this way, the minority carriers 11 generated in the semiconductor layer 10 are accelerated in the first place toward the collecting zone 30 20 and secondly toward the collecting zone 22. When flying under the n-doped collecting zones 20 and 22, the electrons 11 may be trapped by the space charge zone engendered, be collected in the collecting zones 20 and 22 and be tapped off as a measurable electric current by the evaluation device 40, 35 42. The profile of the control voltage as illustrated in

Figure 3c ensures that during a positive control voltage, a drift field is generated which, if the modulated photon flux 50 impinges on the sensor surface, drives the generated electrons 11 to the collecting zone 20. During a positive 5 control voltage, the electrons 11 are accordingly collected at the collecting zone 20, as a result of which a current flow can be tapped off at the collecting zone 20. The profile of the control voltage as illustrated in Figure 3c furthermore ensures that during a negative control voltage, a drift field is generated which, if the intensity-modulated 10 photon flux 50 impinges on the sensor surface, drives the generated electrons 11 to the collecting zone 22. During a negative control voltage, the electrons 11 are accordingly collected at the collecting zone 22, as a result of which a current flow can be tapped off at the collecting zone 22. The 15 profile of the integrated current that results at the collecting zone 20 depending on the impinging photon flux 50 and the control voltage is illustrated in Figure 3d, while the profile of the integrated current that results at the 20 collecting zone 22 depending on the impinging photon flux 50 and the control voltage is shown in Figure 3e.

The evaluation device 40, 42 is formed in such a way that it can determine the sum of the integrated currents that can be 25 tapped off at the collecting zones 20 and 22, which is a measure of the amplitude of the photon flux 50. The evaluation device 40, 42 can likewise determine the ratio of the integrated current that can be tapped off at the collecting zone 20 to the integrated current that can be 30 tapped off at the collecting zone 22, which is a measure of the phase of the photon flux 50 impinging on the sensor with respect to the phase of the control voltage profile illustrated in Figure 3c. If, as is illustrated in Figures 3a and 3c, the phase of the photon flux generated by the 35 transmitter is equal to the phase of the control voltage

generated by the voltage source 60, the ratio of the integrated currents that can be tapped off at the collecting zones 20 and 22 is a measure of the time of flight of the photons from the object to be measured until they impinge on 5 the sensor, and is thus a measure of the distance covered by the photons.

Figure 4 shows an optoelectronic sensor, which differs from the optoelectronic sensor shown in Figure 1 in that instead 10 of the control zones 32 and 34, a capacitor 35 and 36, respectively, is applied on the surface of the semiconductor region 10, to which is applied, by means of an AC voltage source 65, an AC voltage for generating a drift field in the semiconductor region. The capacitors 35 and 36 are spatially 15 separated from the collecting zones 20 and 22, the collecting zones 20 and 22 being arranged between the capacitors 35 and 36. Instead of the capacitors, it is also possible to use Schottky diodes that are reverse-biased.

20 Figure 5 shows an optoelectronic sensor, which differs from the optoelectronic sensor shown in Figure 1 in that instead of the p-doped control zones 32 and 34, n-doped zones 37 and 38 are introduced, which form a pn junction in the semiconductor region 10 and are operated in reverse-biased 25 fashion. An AC voltage is applied to the n-doped zones 37 and 38 by means of an AC voltage source 65 and serves for generating a drift field between the collecting zones 20 and 22. The collecting zones 20 and 22 are arranged in a manner spatially separated from the n-doped zones 37 and 38 and 30 between the latter.

For the rest, the construction of the optoelectronic sensors shown in Figures 4 and 5 corresponds to the construction of the sensors described in conjunction with Figures 1 and 2. 35 Identical reference symbols thus also identify identical

features.

It should furthermore be noted that the collecting zones 20
and 22 of the optoelectronic sensors may be formed as
5 Schottky diodes.